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COMPUTER-AIDED ENGINEERING AND ARCHITECTURAL DESIGN SYSTEM (CAE--ETC(U)
JAN 79 DANIEL, MANN, JOHNSON, MENDENHALL

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COMPUTER-AIDED ENGINEERING AND ARCHITECTURAL DESIGN SYSTEM
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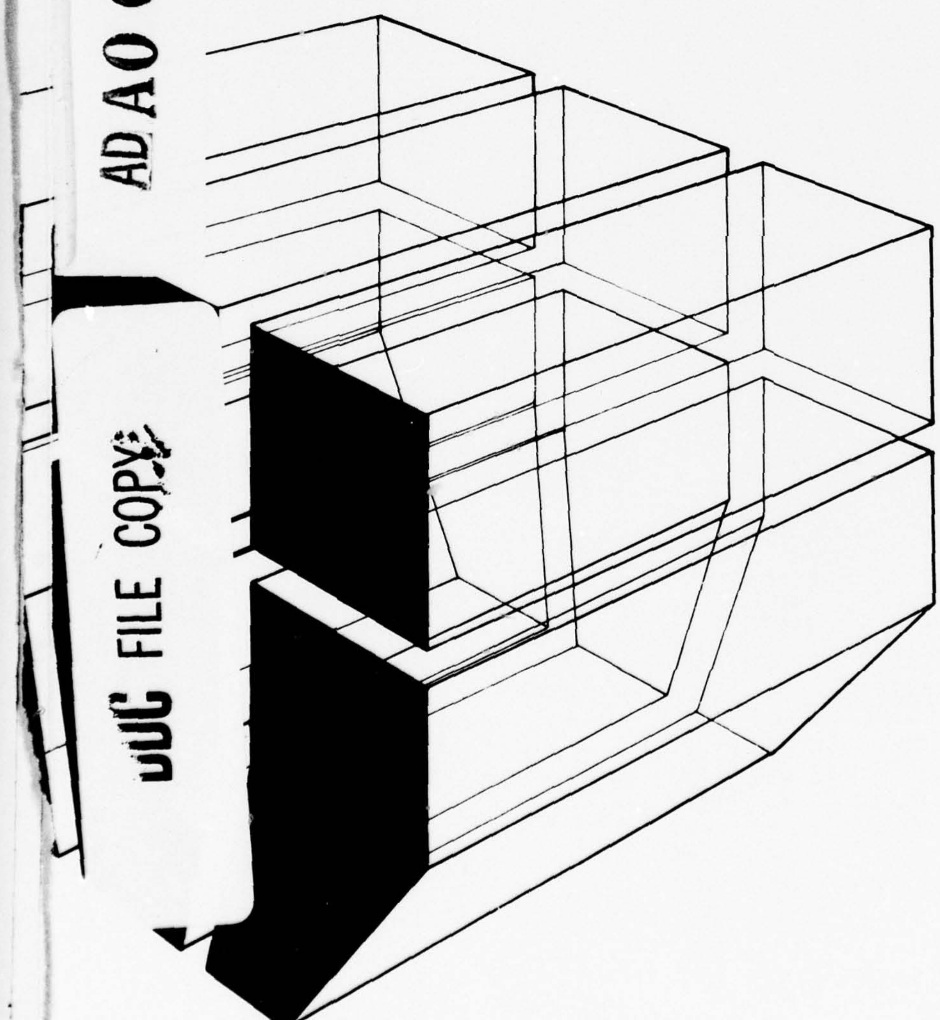

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The Computer-Aided Engineering and Architectural Design System (CAEADS) is being developed for the U.S. Army Corps of Engineers by the Construction Engineering Research Laboratory (CERL) in Champaign, Illinois. This report summarizes the system requirements, preliminary hardware/software systems design, anticipated costs and →

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benefits, project master plan for system development, and study results, conclusions, and recommendations. It also serves as an introduction to Volumes II through VIII, (itemized below) of this series of reports.

CAEADS is an integrated system of computer aids to the design process for military construction, supporting the design and review activities of Corps District Offices and the design activities of private Architect/Engineer firms under contract to the Corps. CAEADS objectives are to improve the quality of facility design, enhance the responsiveness of MC design processes to project needs, improve the productivity of Corps design staff, facilitate design review, and thus reduce the costs of constructing and operating military facilities.

The analysis of CAEADS characteristics in this report concludes that CAEADS design objectives can be realized and that the proposed integrated CAEADS is both technically feasible and economically beneficial. The Project Master Plan proposes that CAEADS development, implementation and use occur in five stages over a period of 12 years. In conjunction with this master plan the CAEADS Economic Analysis compares the current method for MC design (the baseline alternative) to two computer-aided alternative methods (the stand-alone alternative and the integrated CAEADS alternative). This analysis indicates that an integrated CAEADS approach to MC design is most preferable because of increased design productivity and lower construction costs. Therefore, continuation of CAEADS development and implementation in accordance with the proposed master plan is recommended.

The results of this study are reported in eight volumes:

- Volume I - Summary
- Volume II - Concise Review
- Volume III - General Functional System Requirement (GFSR)
- Volume IV - CAEADS Economic Analysis (CAEADS/EA)
- Volume V - Detailed Functional System Requirement (DFSR)
- Volume VI - Project Master Plan (PMP)
- Volume VII - Preliminary Hardware/Software Analysis
- Volume VIII - Organization and Personnel Plan (OPP)

Volume I is written to stand alone, as well as summarize the other volumes. Volume II is also written to stand alone; it is more detailed than Volume I and summarizes Volumes III through VIII. Volumes III through VIII contain detailed technical information of limited interest. Volumes I and II are available through NTIS; Volumes III through VIII can be made available through request to the Technical Monitor.

FOREWORD

This research was conducted by Daniel, Mann, Johnson, & Mendenhall (DMJM) for the Construction Engineering Research Laboratory (CERL), under U.S. Army Engineer Division, Huntsville, Contract Number DACA87-77-C-0009. This work is in support of a system design for a Computer-Aided Engineering and Architectural Design System (CAEADS) being developed under Project 4A762731A741, "Design, Construction, and Operation and Maintenance Technology for Military Facilities"; Task T1, "Development of Automated Procedures for Military Construction"; Work Unit 020, "Computer-Aided Engineering and Architectural Design System (CAEADS)." The applicable QCR is 3.03.004. The Technical Monitor is Mr. V. J. Gottschalk, DAEN-MPE-D, Directorate of Military Programs, Office of the Chief of Engineers. The CAEADS Project Manager is Mr. R. E. Larson of the CERL Facilities Systems Division (FS). Mr. E. A. Lotz is Chief of FS, Col. J. E. Hays is Commander and Director of CERL, and Dr. L. R. Shaffer is Technical Director.

Members of the project staff at DMJM include Perry Grant, David Leckie, Robert Stults, and Lavette Teague. From time to time assistance has been provided by Paul Konkel, Bruce Weinstein, Max Farrar, Stanley Katten, Ernest Swickard, and Michael Durkin. Architects and engineers within DMJM who have provided their time and talents include Derek Anderson, William Ropp, Anthony Lumsden, Jerry Tomlin, Thomas Saeda, William Meier, Jack Meadville, and Sam Lo. James Davis and Howard Kanter of Banneker, Davis, and Associates in Chicago assisted in CAEADS hardware analyses.

Providing valuable input to this study were Mary Oliverson of Applied Research of Cambridge (ARC), Canada; William Mitchel of ARC (via UCLA), Guy Weinzapfel of MIT, and Monte Miller of the Federal Computer Performance Evaluation and Simulation Bureau (FEDSIM). In addition, several others provided important review comments during this study, including Charles Eastman and Steven Fenves of Carnegie-

Mellon University, Louis Klotz of the University of New Hampshire, and James White of NASA.

Appreciation is extended to the engineering and design staffs at the Sacramento District Office (under the direction of Mr. Lou Santin) and the Mobile District Office (under the direction of Mr. Richard Mueller) for providing valuable advice and information on the MC design process and procedure used in engineering and architectural design within the Corps of Engineers.

CONTENTS

CONTENTS (continued)

FIGURES

TABLES

CHAPTER 1

INTRODUCTION

a. Summary Report Purpose and Scope. The purpose of this report is to introduce the Computer-Aided Engineering and Architectural Design System (CAEADS) concept and summarize the results of the system study performed for the U.S. Army Construction Engineering Research Laboratory (CERL) as part of the overall CAEADS program.

This volume presents highlights of the Military Construction design process, CAEADS requirements, system concept and preliminary design, economic analysis, proposed project master plan and the results, conclusions and recommendations of this study.

b. Study Purpose. The purpose of the study is to develop the Planning and Definition Phase documentation (as defined by AR 18-1) for a CAEADS to support Army military construction. Planning and definition documentation concerns functional and resource (time, funds, manpower, and material) requirements.

c. Study Scope. This study addresses the technical and economic feasibility of an integrated CAEADS and its application to the MC design process. It encompasses the development of a new facility from the initial identification of needs and project requirements to the eventual preparation of contract plans, specifications and cost estimates.

d. CAEADS Objectives and Guidelines. CAEADS is to be a system of computer aids to the MC design process beginning with the definition of requirements for a project and extending through the preparation of construction plans, specifications, and cost estimates. CAEADS products are to include documents required for evaluation and approval of proposed construction projects and execution of architectural

and engineering design, as well as all design documents included in the bid package for facility construction. Documents produced by the CAEADS-aided MC design process are to be as similar as possible to those produced by the current process.

CAEADS is to provide improvement in design productivity, quality and efficiency of design solutions, and responsiveness to project requirements and is to facilitate design review, thereby reducing the costs of design, construction and facility operations.

The primary users of CAEADS will include planners, architects, engineers, specifiers and cost estimators in the Office of the Chief of Engineers, Engineer Divisions and District Offices. CAEADS will also support the Military Construction (MC) design roles of U.S. Army major commands (MACOMs) and Facility Engineers at Army installations. Because approximately 80 percent of MC design is performed by private sector architectural/engineering (A/E) firms under contract to the Corps of Engineers, CAEADS will also support these participants.

CAEADS must have simple and common human-machine interfaces, interface with existing ADP systems, be integrated, modular and flexible in nature, and provide expandability. It is to be designed for open-ended evolution in scope and effectiveness, and to minimize the impact of advances in computer hardware and software throughout the life of the system. Because of the broad scope and complexity of CAEADS, system design, development, and implementation are to be phased over a number of years, proceeding incrementally in accordance with the Project Master Plan. Throughout this period of evolutionary development and implementation, the system is to provide continuity of user support and common human-machine interfaces.

e. CAEADS Background. Development of computer applications to architectural and engineering design began approximately two decades ago with the initial commercial availability of digital computers. During the 1960's research at universities and industrial laboratories produced major advances in human-machine communication through the development of problem-oriented languages, interactive computer graphics, and time-shared computing. Research and development toward integrated systems for use

in building design have been pursued for at least the past 15 years.

Computer aids to building and site design in the form of stand-alone applications programs for specific types of design and engineering calculations are currently in widespread use in this country and abroad. However, no complete integrated system with the scope of CAEADS has yet been developed.

Work toward CAEADS has been in progress at CERL for the past four years, preceded by four years of development of computer programs for design-related tasks.

The most recent CAEADS effort, which began in January 1977, is summarized in this report. Its objectives were to develop functional requirements for CAEADS in greater detail, to perform an economic analysis, to suggest alternative hardware configurations based on functional requirements, to prepare an action plan for subsequent system development and implementation, and to further develop the CAEADS system concept to be used as a basis for advanced system design. A concurrent study investigated the special requirements of three-dimensional data bases for use in computer-aided facility design[1].

f. Study Products. The products of this study are:

(1) General Functional System Requirements (GFSR), including:

Detailed description of current MC design processes

Detailed description of proposed CAEADS processes

Analysis of Corps MC design workload

CAEADS functional requirements

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[1] Mitchell, W.J., Oliverson, M., Computer Representation of Three-Dimensional Structures for CAEADS, Technical Report P-86/ADA052040 (CERL, February 1978).

(2) Detailed Functional System Requirements, including:

CAEADS functional hierarchy

Detailed description of system functions

Description of CAEADS system components (data bases, etc.)

(3) Economic Analysis (EA), including:

Analysis of three alternative MC design alternatives (baseline alternative, stand-alone alternative, and integrated CAEADS alternative)

Comparison of alternatives

Recommendation of best alternative.

(4) Project Master Plan (PMP), including:

Development schedule

(5) Preliminary description of CAEADS hardware requirements and system configuration.

(6) Organization and Personnel Plan (OPP) - performed by CERL.

These study products are shown diagramatically in Figure 1-1.

g. Mode of Technology Transfer. This information will be disseminated in accordance with procedures set forth in AR 18-1, Management Information Systems: Policies, Objectives, Procedures and Responsibilities (Department of the Army, 22 March 1976).

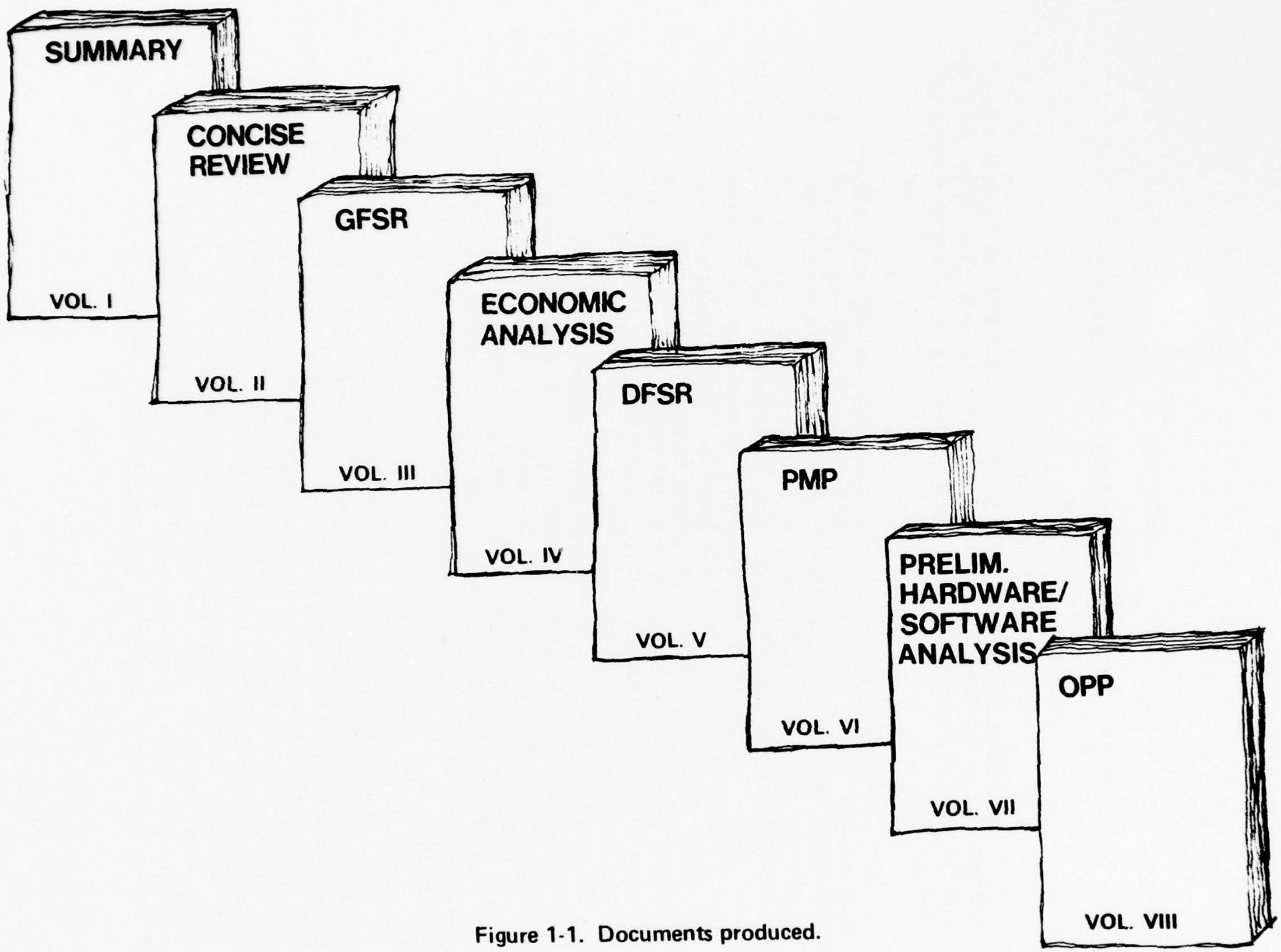


Figure 1-1. Documents produced.

CHAPTER 2

MILITARY CONSTRUCTION DESIGN

a. Current Manual System. Military construction design is performed by the Corps of Engineers (CE) and by architectural and engineering firms (A/E) under contract to the Corps.

Within the Corps, the Office of the Chief of Engineers (OCE) develops criteria, regulations, technical manuals, and guidelines for Military Construction. The Engineer District Office is the organizational level primarily responsible for the design of facilities for the U.S. Army, U.S. Air Force, and other U.S. and foreign government agencies as assigned. The Districts perform studies for construction proposals, execute design for approved proposals, prepare detailed cost estimates and construction documentation, and review work produced by both Corps and contract designers. Some Districts also perform technical analysis and determine functional requirements for facility design where necessary. Figure 2-1 represents a simplified design process in which a District Office or A/E firm will first analyze the design requirements and produce a design solution, followed by the generation of design documents which in turn are used to construct the new facility.

Participation of Army and Air Force major commands in the MC design process occurs prior to design. Major commands identify facilities needed to support their mission and must approve proposed projects before they can be included in Army construction design programs. The Facility Engineer at each installation is responsible for defining the user's requirements for each proposed facility in order that the project can be evaluated and an adequate budget for design and construction can be established for approved projects. If a project is approved, the Facility Engineer

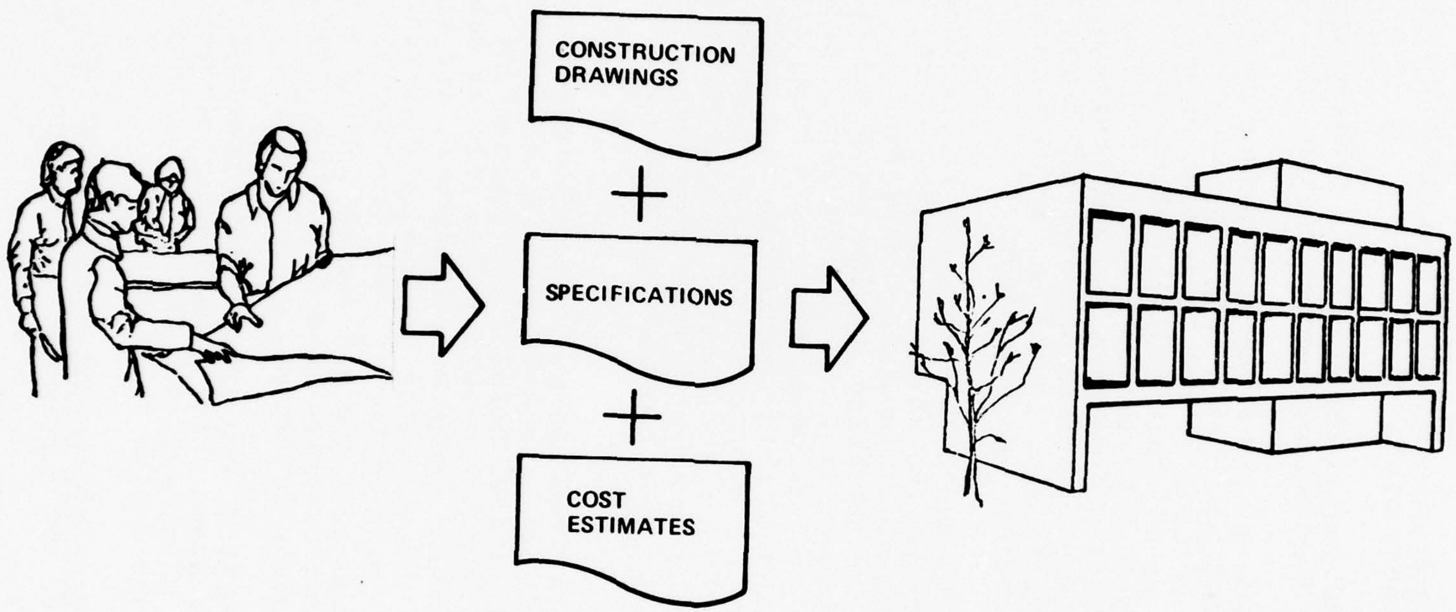


Figure 2-1. MC design process.

is responsible for its inclusion in updates to the Installation Master Plan.

The MC design process for a project consists of three phases: Pre-Design, Concept Design, and Final Design.

The Pre-Design Phase encompasses preparation of all documents and activities from the time the need for a facility is identified by the Department of the Army, a Major Command, or an individual installation, until the beginning of Concept Design by a District Office or an A/E firm. It includes the preparation and review of the documents required to obtain approval to design the facility as well as the determination of the requirements and criteria applicable to each project.

In the Concept Design Phase the designers investigate alternative spatial configurations as well as structural, mechanical, and electrical systems, and select the combination of facility configuration and systems which best satisfy project requirements. Analysis procedures concentrate on evaluation of trade-offs among alternatives. At the conclusion of this phase there is a review by the District Office for conformity to user requirements, design criteria, and the project budget. The products of this phase are a set of concept design drawings, a cost estimate, and a list of the specification sections to be prepared later.

In the Final Design Phase the approved concept design is developed into a detailed final design for the facility. This phase includes the engineering analyses and synthesis of the major subsystems as well as detailed decisions about the materials, equipment, and components of the facility. The products are design drawings, specifications, and a detailed cost estimate. The drawings and specifications are incorporated into the bid package which is the basis for the construction contract, and the cost estimate is the source for the government estimates.

Not all MC projects conform precisely to the three phases defined above. For some complex projects, the Final Design Phase is subdivided. For simple projects, there may be only a single design phase.

b. Alternative Computer Aids To MC Design. Two alternatives to the current MC design process which provide

computer aids to MC design were evaluated in this study: the stand-alone alternative and the integrated CAEADS alternative. Both concepts were developed for comparison with the current manual system (baseline alternative) in terms of costs, benefits and economic performance. The baseline alternative was included to provide the basis of comparison for the other two alternatives.

(1) Stand-Alone Programs. A number of specialized computer aids to MC design have been under development by CERL for about four years. A stand-alone system is characterized as a separate computer aid that supports a particular function, element or discipline involved in any or all of the three phases in the MC design process: Pre-Design, Concept Design, and Final Design. These programs operate independently without interaction with other programs. These programs perform tasks related to engineering calculations, specification preparation and text editing, evaluation of environmental impacts, preparation of cost estimates, and semi-automated graphics production. A major difficulty inherent in the baseline alternative (which would still be present in the stand-alone alternative) involves communication and coordination among the various disciplines that participate in the MC design process. In these two alternatives, communication and coordination between disciplinary specialists is left to the individual and often involves the manual transfer of complete or semi-complete work. Coordination at a detailed level often does not take place until this work is substantially complete, thereby requiring major revisions where conflicts exist. Similarly, independent specialists are dependent upon information which should be up-to-date and complete. This dependence on manual communication through substantially completed documents introduces additional possibility for design conflict and project delays. Unfortunately, due to the large number of participants, continuing changes and refinements developed during the design process, and the complexity of some projects, it is virtually impossible for this function to take place as required. Lack of adequate communications and coordination results in design errors and inconsistent or conflicting information on construction documents. This results in bid package addenda frequently requiring rebidding after the initial bid package has been put out to contractors, causing delays and additional costs.

(2) Integrated CAEADS. A fully integrated system of computer aids to design such as CAEADS consists of a set of applicable programs using common computer data bases and computer hardware. All programs communicate with each other and have common standards and user interfaces with computer hardware and software subsystems. CAEADS minimizes the communications and coordination problem by providing a common data base that is automatically kept up to date as design proceeds. All design participants using computer aids automatically draw upon this common data base so that information used is standardized and up to date. This information is easily and quickly accessible through CAEADS terminals. Any change to a project will be rapidly reflected in all relevant data bases and design files. Changes which create a conflict with existing project data will not be accepted, thus assuring compatibility among subsystems previously designed by various disciplines.

In the proposed CAEADS concept, many of the stand-alone programs presently under development will be incorporated and integrated into the system.

Figure 2-2 is a second representation of the design process, showing that the introduction of computer aids will only affect the process of establishing a design solution and generating the documentation to support the solution. Required project documentation and construction procedures will remain unchanged.

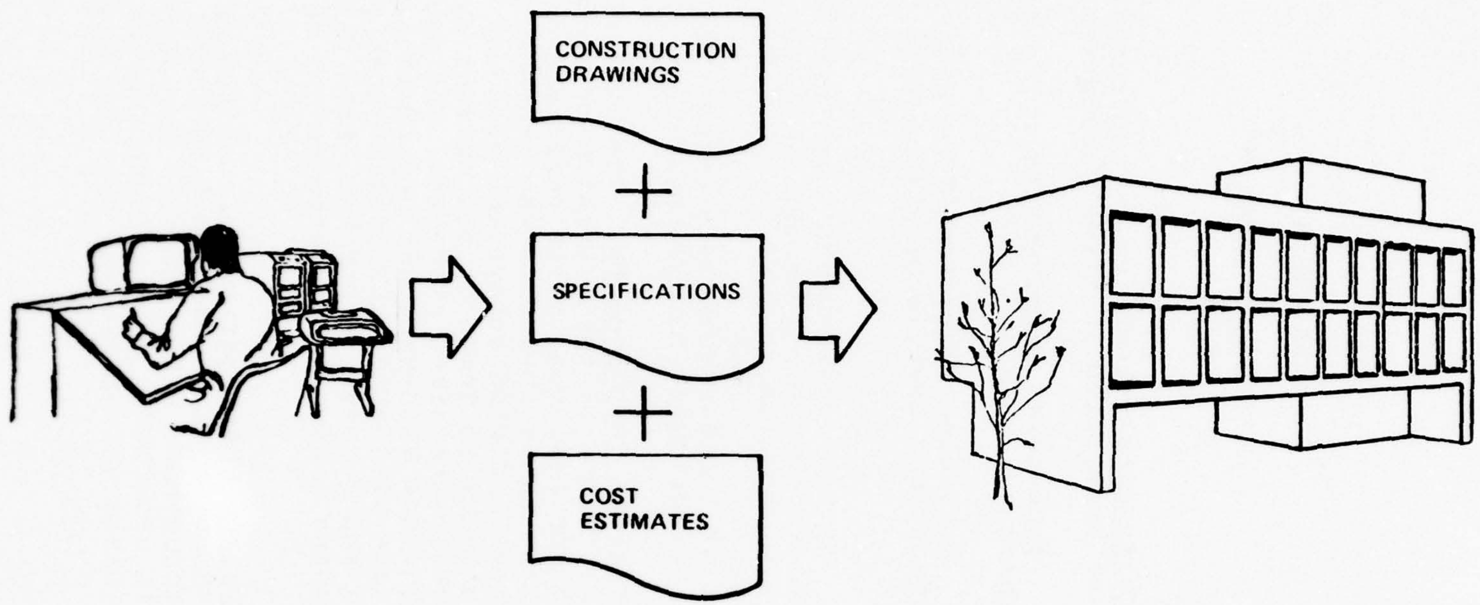


Figure 2-2. CAEADS design process.

CHAPTER 3

CAEADS REQUIREMENTS

a. Requirements Categories. Requirements for CAEADS development are summarized in three categories:

(1) Functional requirements for direct support MC design functions;

(2) Operating characteristics governing human-machine interfaces and user interactions with the system; and

(3) System requirements which will evolve over a 12-year period during which advances in computer software and hardware are expected.

Each of these requirement categories is briefly discussed in the following paragraphs.

b. Functional Requirements. The over-riding requirement for CAEADS is the provision of computer-aided support to professional activities performed as part of MC design during the three phases of the process in a completely integrated manner. CAEADS subsystems must aid production of end products similar to those of the current system as well as a variety of intermediate products. The system must include or interface with external applications software. It must interface with other ADP systems that provide information to and receive information from CAEADS, and provide processing hardware and software not contained within CAEADS.

c. Operating Characteristics. CAEADS must provide simple and consistent human-machine interfaces and interactions throughout all subsystems for all users, including: (1) architects and engineers who perform MC design, specialists who update and maintain data bases at

OCE and District Offices, and Facility Engineers and other personnel at MACOM and OCE involved in the pre-design phase; (2) support personnel who initialize and maintain up-to-date data bases, and software libraries, which control backup information, and which administer the system, authorizing access to subsystems and data bases; and (3) system and subsystem development personnel who maintain CAEADS, correct errors, develop new software, and modify the system to incorporate advances in hardware and software technology using high-level software aids that assist in development of error-free applications and subsystems.

Within each of these categories of users there are likely to be individuals who vary in familiarity and sophistication in the use of computer-aided systems in general and CAEADS in particular. CAEADS must provide tutorial dialogue, cues and prompts. These features will assist all users in obtaining aid from CAEADS subsystems efficiently and effectively.

d. System Requirements. CAEADS must contain a common and uniform set of information processing capabilities that meet specialized functional and human factors requirements in a thoroughly consistent manner. System-level features must provide high level tools for the orderly and efficient growth and development of CAEADS over time.

System software must support the creation, maintenance, updating and purging of data bases, provide controlled and selective access to data bases for storage and retrieval of information, and provide access to data bases from applications software and a user query language.

Data bases must accommodate text, tabular, alphanumeric, graphic and three-dimensional information that describes project facilities and sites.

CAEADS processing capabilities must include text editing and document preparation, computationally intensive decimal floating point calculations, geometric data manipulation, graphic representations for displays and drawing preparation, cost estimate tabulations, and reports consisting of alphanumeric and tabular data. It must employ uniform software for application programs requiring similar processing types.

The system must provide for communications between District and regional processors, access by contractor A/E firms, and links to remote processors for special purpose software existing outside CAEADS.

CAEADS must accommodate a variety of terminal types in a highly device-independent manner. User command language must be standardized to provide a common user interface and to facilitate a command language definition capability that will serve as a high-level tool for extending the repertory of user commands.

The system must facilitate management by data base and system administrators of program libraries, system files, catalogues and data bases. Records of the use of system resources must be provided in order to allocate costs to users and projects, and to identify areas in which modifications can improve response, efficiency, and system throughput.

CAEADS must incorporate flexibility for orderly growth and evolution through modularity, carefully controlled internal and external interfaces, uniformity and commonality of software, a high degree of machine and device independence, use of appropriate programming language, and high-level system-building software.

Finally, CAEADS must provide system and data security, thereby guarding against destruction of programs, data bases and other system features either willfully, accidentally or due to natural catastrophes such as fire, earthquake or flood. Proper administration of system use and regular maintenance of backup information external to the system are major elements of system security and protection. Maintenance of data integrity must be carefully designed into a system software and processing because of the multi-user, simultaneous access and dynamic modification of shared information such as the Facility Description.

CHAPTER 4

CAEADS DESIGN

a. Concept and Hierarchy. Based on the preceding requirements for support of the MC design process by computer aids, the following overall concept for CAEADS has been developed. The system will be project- and District-oriented while providing periodic review and timely updating to Corps-wide standards, guidelines and criteria. The CAEADS hierarchical structure is shown in Figure 4-1 which depicts the four levels of the CAEADS hierarchy. Figure 4-2 is a further analysis of the components included in each level of the hierarchy, showing the three design phases in the inner ring, the nine activity areas in the middle ring, and the eight design disciplines in the outer ring. Using Figure 4-2 it is possible to model the many possible combinations of project type, phase, activity, and discipline which may occur in the course of a design effort. The combinations are constructed by relating a single characteristic in a ring to a single characteristic in each of the other concentric rings or levels of the diagram. Each of these combinations represents a unique function which may occur in the design process.

In the pre-design phase of MC design, CAEADS will facilitate the preparation of DD 1391 forms and associated cost estimates in order to expedite the review of facility needs and the approval of projects for design. Upon approval, installation master plans will be updated to reflect the proposed new construction. CAEADS applications will interface with Army installation information systems for facility engineering and with the proposed Corps data base for installation master planning.

During concept and final design phases, CAEADS will support the work of designers at District Offices and in private architectural and engineering firms. Selected District Offices will have a dedicated computer, sized to

LEVEL ONE	DESIGN PROJECT
LEVEL TWO	DESIGN PHASES
LEVEL THREE	DESIGN ACTIVITIES
LEVEL FOUR	DESIGN DISCIPLINES

Figure 4-1. Levels of CAEADS hierarchy.

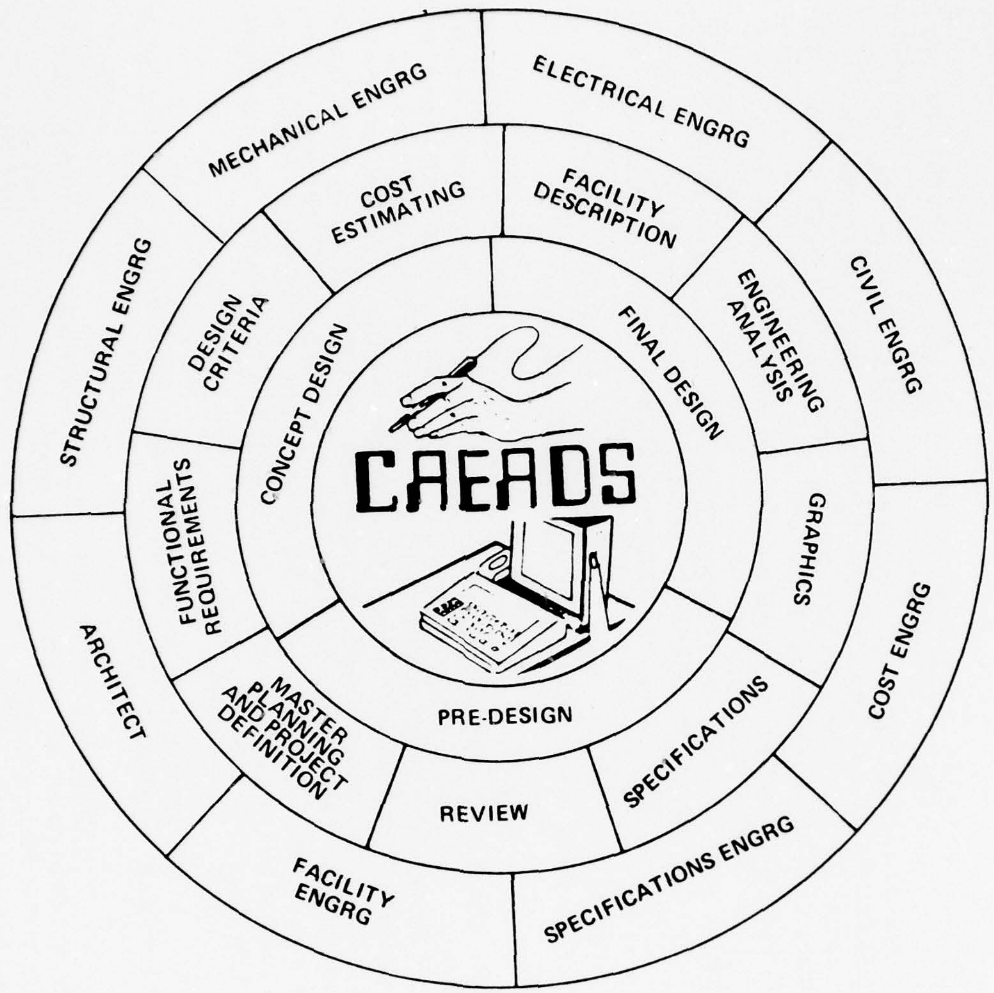


Figure 4-2. Detailed CAEADS hierarchy.

accommodate project workload with allowance for peak loads, operating between 8 and 12 hours per day. The system will assist with Facility Descriptions, Engineering Analysis and Synthesis, Specifications, and Cost Estimates. A variety of terminals and input/output devices will promote communication between the CAEADS user and the computer through command and query languages. Graphics support will be provided for both interactive displays and finished drawings.

b. Preliminary System Description. Central to each project in CAEADS is a computer-resident Facility Description stored at the District computer. This will be the primary repository of design information for coordination and integration of the effort of the project design team. All members of the team will be working from the same consistent and current data base defining the facility configuration and the physical elements from which it is to be constructed. Models used in the analysis of circulation patterns, structure, energy consumption, electrical power distribution, lighting, and other building subsystems will be derived from the shared Facility Description data base. Plans, elevations, sections, and detail drawings will be produced directly from the Facility Description, and thus will be consistent.

In addition to the District computer installations, two regional CAEADS processing centers are proposed, each serving a designated group of Districts. These centers will provide processing services for specifications and other documents produced during MC design which require extensive text editing capabilities such as project development brochures, functional requirements, design criteria, and review comments. The regional centers will also provide computing resources for engineering analyses and synthesis which cannot be accommodated by the District computers.

A schematic system design, including the District Office and regional processors, is shown in Figure 4-3.

c. Software. The principal emphasis in developing CAEADS software will be on the provision of a system framework which makes integration of design functions possible and which fosters flexible growth and extension of CAEADS. System software must meet CAEADS requirements for

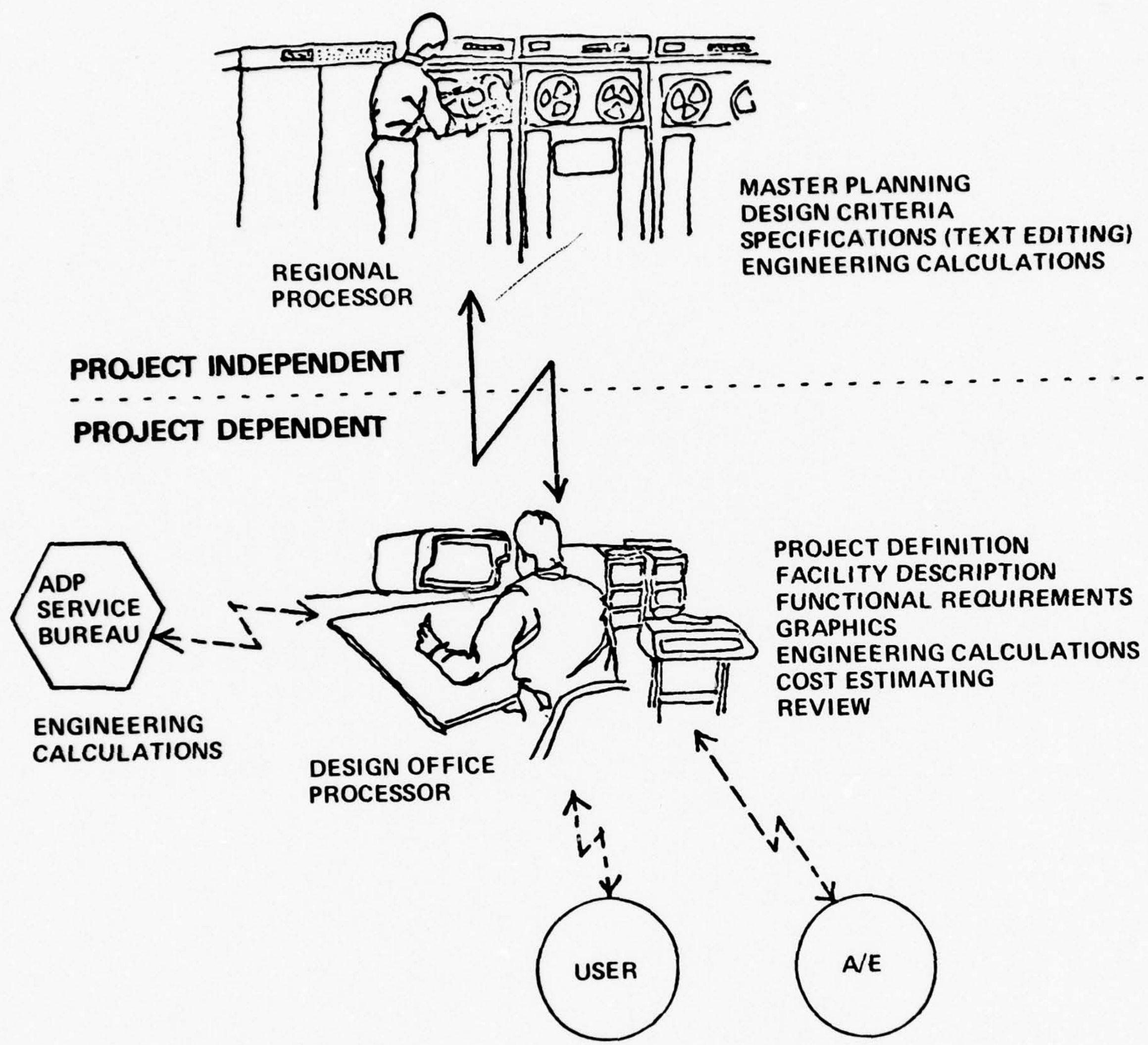


Figure 4-3. CAEADS equipment schematic.

user interaction, facility description, data management and engineering applications.

To facilitate effective user interaction as well as produce the required intermediate and end products, CAEADS will incorporate a variety of standardized terminal types. At these terminals the user will communicate with the system through a command language. The language will be compatible with the terminology of the professional disciplines and usable across the variety of input terminals. Patterns and protocols for user interaction will be common to all CAEADS subsystems and programs. CAEADS standards for user interfaces will promote continuity and uniformity of user interaction throughout the evolution of the system.

Various categories of applications software are needed for direct support of the variety of professional disciplines within the MC design process. Some of these software packages or subsystems will be contained within CAEADS. Others will be operational on outside hardware and require an interface with CAEADS. These latter programs include proprietary software which is unavailable for direct incorporation into CAEADS and software which is too specialized or too infrequently used to be maintained in CAEADS.

Flexibility for CAEADS evolution will be achieved through modularity and commonality of software. Commonality of software is exemplified by the use of a single program for all text processing and document editing applications, such as editing of specifications, preparation of Project Requirements or Design Criteria. The higher the level at which uniformity and commonality can be achieved, the simpler the maintenance of software, the greater the reliability, and the lesser the impact of software modifications on system efficiency. In Engineering Analysis and Synthesis, uniform software for all flow networks such as HVAC ducts, water, steam and gas distribution systems, plumbing, and waste and drainage systems can provide similar benefits. It is also necessary that the three-dimensional data base being developed by CERL for installation master planning and utility analysis conform to the CAEADS facility and site description data bases.

d. Hardware. CAEADS hardware, like CAEADS software, must be modular due to anticipated growth in system usage

and due to the diversity of processing volumes at the various District Offices and at OCE. CAEADS hardware consists of two regional processors and eight Design Office processors located at eight select District Offices (see Figure 4-3).

The District Office hardware used for interactive Facility Description and Engineering Analysis and Synthesis will include keyboards and graphic display devices, terminals for document editing and preparation, and plotters for drawing production.

Each set of District work stations will be served by a large minicomputer with floating-point processor, memory in the range of 512,000 bytes, and direct-access storage of approximately 320 million bytes for project data bases. Approximately 25 to 30 of these minicomputers will be required throughout the Corps, with two or more per District depending upon project workload. District minicomputers will also manage communications with Facility Engineers at Army installations, with the regional processing centers, and with outside services used for remote processing of specialized engineering applications. The cost of hardware for an average District with three minicomputers is estimated to be approximately $1,000,000.

Each of the two regional processing centers will contain a medium-scale computer for both document editing and engineering computations. These machines will store the OCE and District data bases for Functional Requirements, Design Criteria, Master Specifications, and construction cost elements as well as the project-specific Functional Requirements, Design Criteria, and Specifications for their respective Districts. They will also support communications with the District computers and perform engineering analyses which are too large or time-consuming to be carried out on District machines. The size of each regional computer is anticipated to be 1,024,000 bytes of memory with direct-access storage of approximately 1.5 billion bytes. The cost of each installation is expected to be in the range of $1,000,000.

CHAPTER 5

CAEADS ECONOMIC ANALYSIS

a. Scope and Approach. The CAEADS Economic Analysis (CAEADS/EA) consisted of the development and assessment of costs and benefits associated with three MC design system alternatives: the baseline alternative, the stand-alone alternative, and the integrated CAEADS alternative. These alternatives were evaluated over a 12-year development/use period (FY 1978 through FY 1989). Included in the analysis were operations costs, applications design costs, system design costs, and hardware/software procurement costs. Benefits attributable to each alternative were identified as either design benefits or construction benefits. Further benefits, identified as intangible or non-quantified benefits, were described in the analysis but did not affect the economic comparison of the alternatives.

b. Analysis Procedures. The analysis compared the costs and benefits of the three alternatives. The baseline system represented the current method of performing MC design, the stand-alone alternative introduced independent application programs to aid the MC design process, and the integrated CAEADS alternative proposed an integrated system of applications programs which utilized common data bases and standard system interfaces. Each alternative was evaluated using an estimated annual project workload of 600 typical projects. A description of the typical project is given in Table 5-1. A summary of the design effort required for this typical project in each of the system alternatives is shown in Table 5-2.

The incremental costs for the development, implementation and use of the stand-alone alternative and the integrated CAEADS alternative are summarized in Table 5-3. These costs reflect the incremental difference between the two proposed alternatives and the baseline alternative for applications program design costs, system design costs,

Table 5-1

PROFILE OF TYPICAL PROJECT

Construction Costs		$1,250,000
Design Costs		$ 75,000
Design Effort (hours)		
Pre-Design Phase	338	
Concept Design Phase	900	
Final Design Phase	1962	
Total Design Effort		3,200 hours
Square Footage		25,000 sq. ft.

Table 5-2

ANALYSIS OF DESIGN EFFORT BY ALTERNATIVE METHODS FOR MC DESIGN

	Manual (Hours)	Stand-Alone (Hours)	CAEADS (Hours)
DESIGN ACTIVITY - CE			
Master Plan and Project Definition	96	80	64
Functional Requirements	64	48	40
Review	192	192	160
TOTAL HOURS (% efficiency)	352 (100.0)	320 (110.0)	264 (133.3)
DESIGN ACTIVITY - CE AND/OR A/E			
Design Criteria	96	64	40
Architectural Design	208	208	0
Facility Description	0	0	540
Engineering Analysis and Synthesis	800	688	400
Graphics	1,296	640	320
Specifications	224	160	144
Cost Estimating	224	192	128
TOTAL HOURS (% efficiency)	2,848 (100.0)	1,952 (145.9)	1,572 (181.2)
OVERALL TOTAL HOURS (% efficiency)	3,200 (100.0)	2,272 (140.8)	1,836 (174.3)

Table 5-3

SUMMARY OF INCREMENTAL COSTS
FOR THE
STAND-ALONE ALTERNATIVE
AND THE
INTEGRATED CAEADS ALTERNATIVE
OVER THE 12-YEAR PERIOD
($ 000)

	Stand-Alone	Integrated
Applications Design	25,689	28,528
System Design	0	7,910
Procurement	8,154	15,687
Operations and Use	11,169	35,730
TOTAL COSTS	45,012	87,855

hardware and software procurement costs, and operations and use costs.

The tangible benefits quantified in this analysis are summaried in Table 5-4. These benefits are categorized as design benefits and construction benefits. Design benefits result from the reduction of design effort (see Table 5-2), and the reduction of technical errors which occur in design. Construction benefits result from lower construction costs due to complete and consistent documentation.

Additional benefits which are intangible or were not quantified in this analysis include improved quality of end-products, more efficient use of space and reduction of spatial conflicts, greater conformance to Corps requirements and criteria, greater consistency and standardization of end-products, improved control and coordination of design activities, enhanced design review capabilities, and improved operations and maintenance of facilities. These benefits are elaborated upon in Volume IV of this report.

c. Results. The results of the Economic Analysis are presented in Figures 5-1 through 5-4. Figures 5-1 and 5-2 show the cash flow characteristics for the stand-alone and integrated CAEADS alternatives, respectively. In each case, the performance of the alternative considering design benefits only is compared to the performance of the same alternative considering total (design and construction) benefits. Also indicated in these figures are the benefit-cost ratio (B/C) and the return on investment (ROI).

Figures 5-3 and 5-4 compare the performance of the stand-alone and integrated CAEADS alternatives. Figure 5-3 shows the two alternatives considering all costs and only design benefits. Figure 5-4 compares the two alternatives considering all costs and all benefits (design and construction).

Table 5-5 summarizes the results of the comparison of the stand-alone and integrated CAEADS alternatives with the baseline alternative. Listed are the incremental costs and sunk costs for development, implementation and use for each alternative over the 12-year development/use period. Estimated benefits that result from improved design efficiency and reduced construction costs are also shown. The bottom half of the table lists the effects that each

Table 5-4

SUMMARY OF INCREMENTAL BENEFITS
FOR THE
STAND-ALONE ALTERNATIVE
AND THE
INTEGRATED CAEADS ALTERNATIVE
OVER THE 12-YEAR PERIOD
($ 000)

	Stand-Alone	Integrated
Design Benefits	105,090	179,968
Construction Benefits	48,766	180,368
TOTAL BENEFITS	153,856	360,336

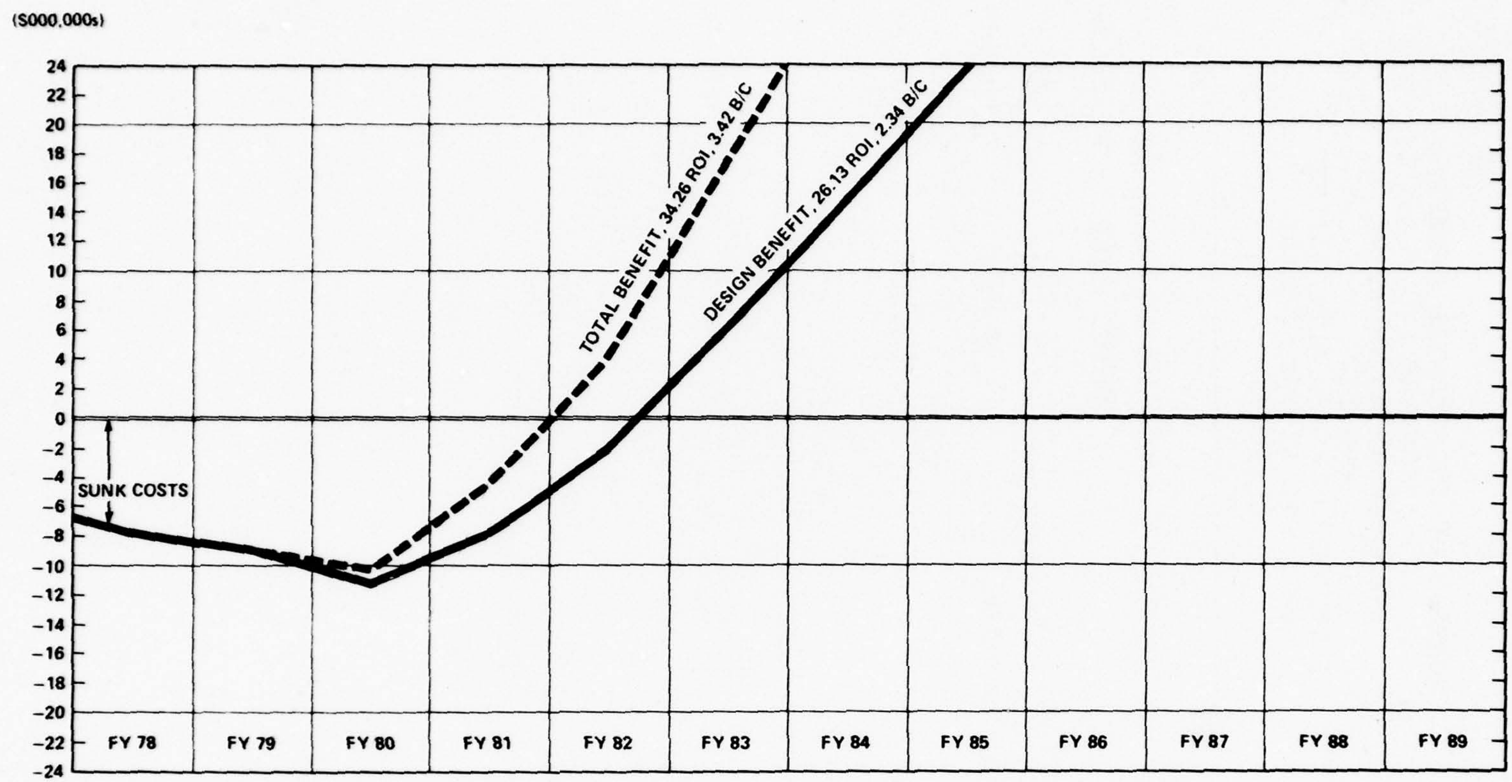


Figure 5-1. Comparison of estimated cash flow for stand-alone systems.
(total benefit vs. design benefit only, at 40 percent improved efficiency)

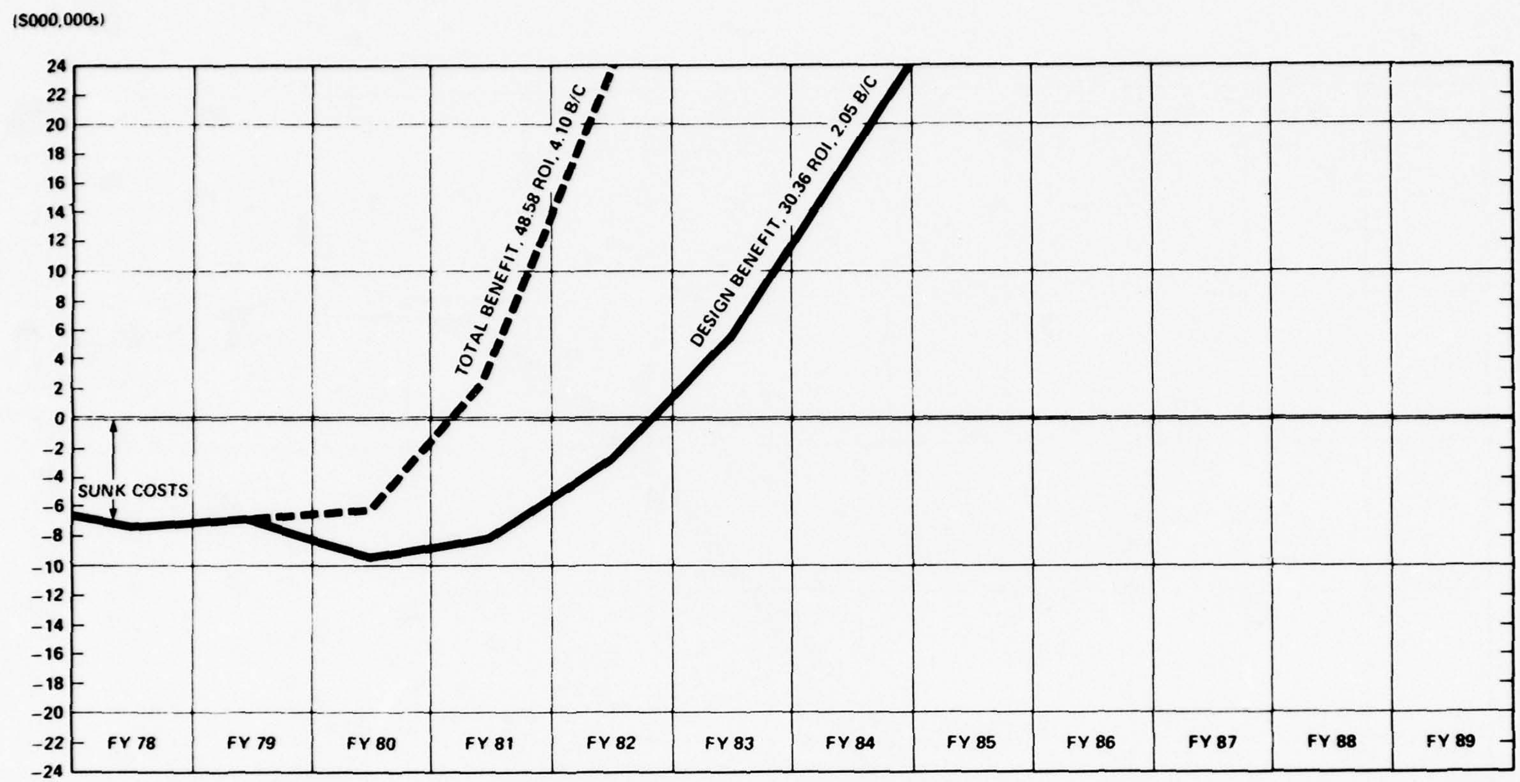


Figure 5-2. Comparison of estimated cash flow for CAEADS systems.
(total benefit vs. design benefit only, at 75 percent improved efficiency)

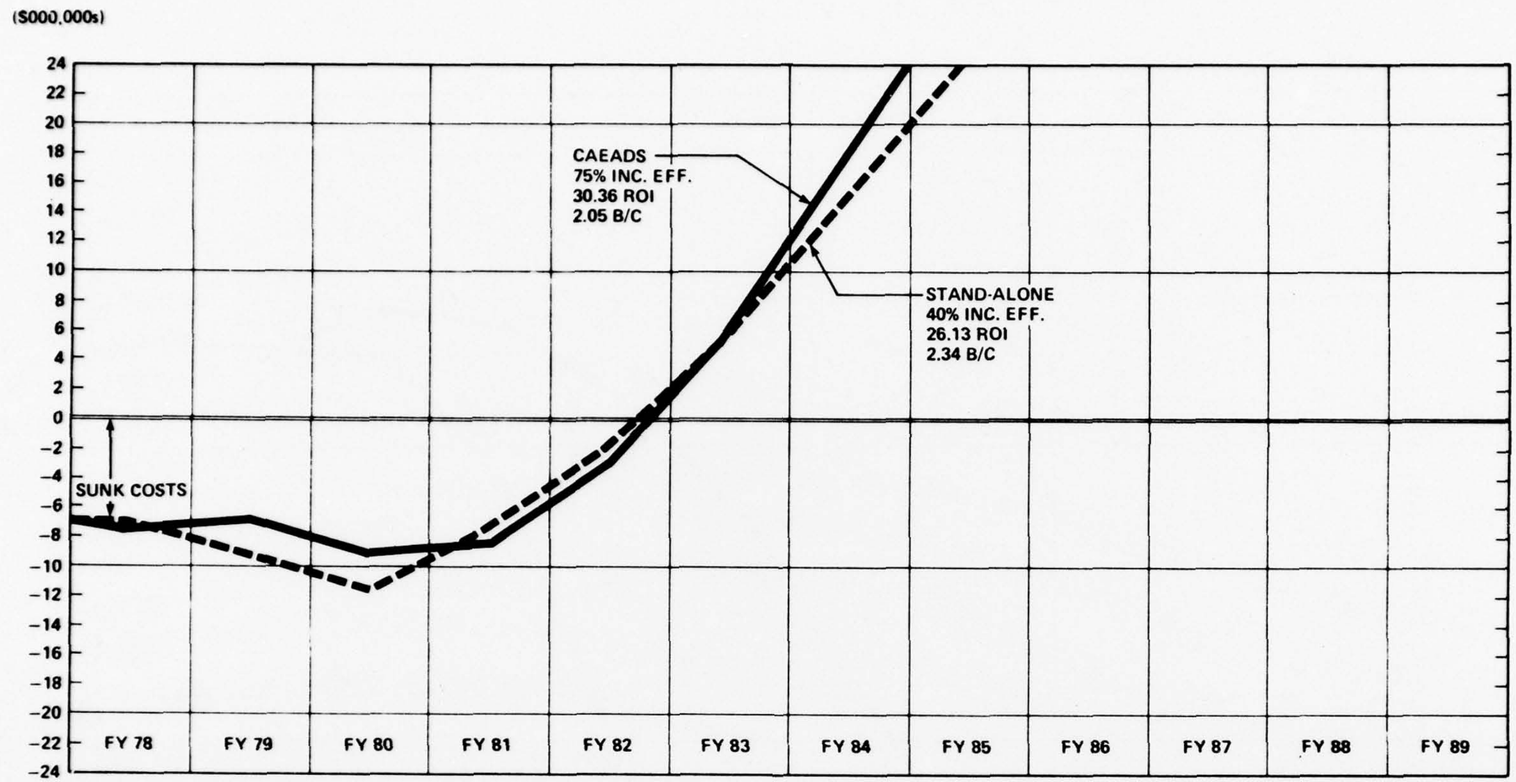


Figure 5-3. Comparison of estimated cash flow for CAEADS and stand-alone alternatives – design benefits only.

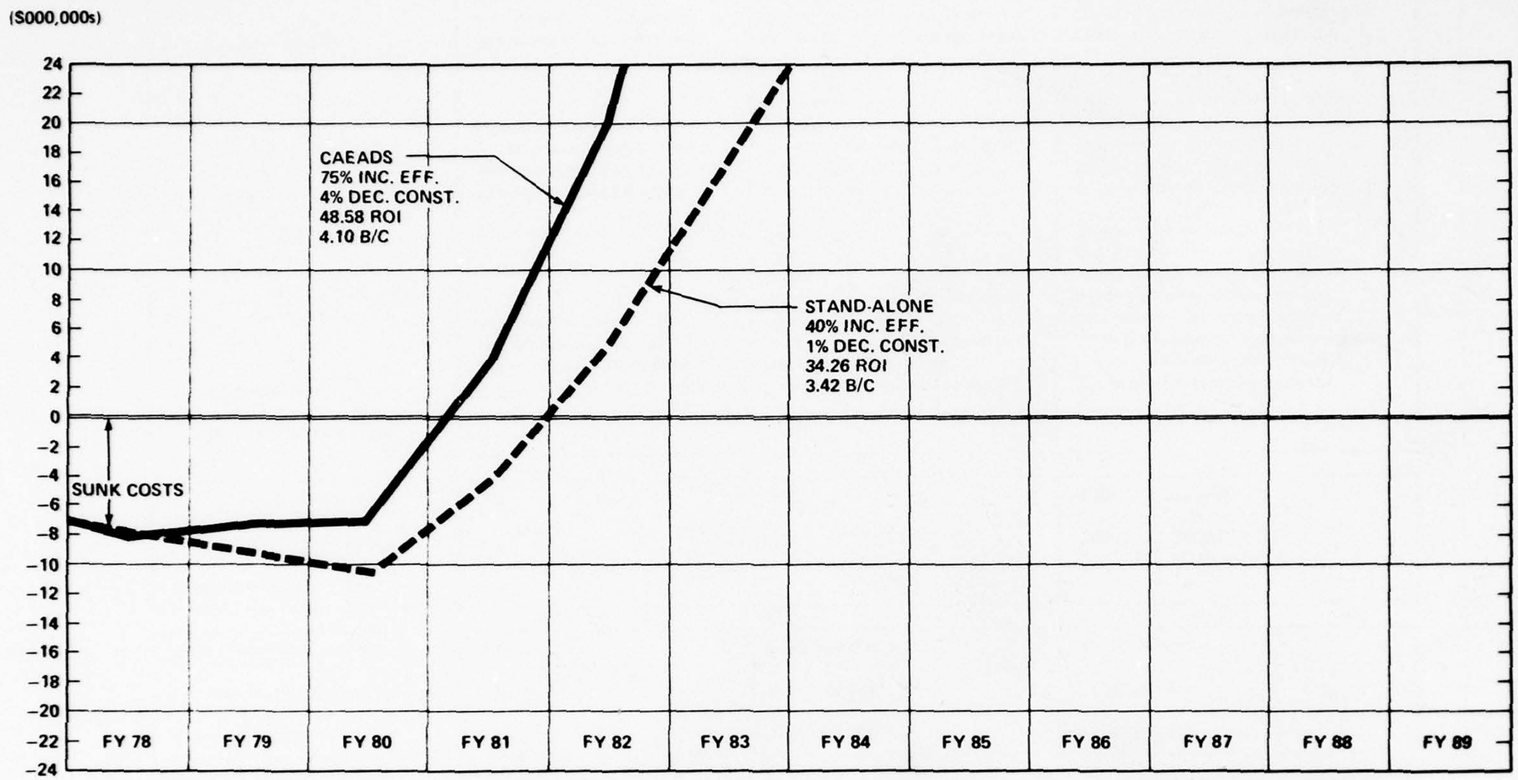


Figure 5-4. Comparison of estimated cash flow for CAEADS and stand-alone alternatives – total benefits.

Table 5-5. SUMMARY OF COMPARISON OF ALTERNATIVES

	BASELINE ALTERNATIVE	STAND-ALONE ALTERNATIVE	INTEGRATED CAEADS ALTERNATIVE
Incremental Cost	$ 0	$ 45,012,000	$ 87,855,000
Sunk Cost	$ 0	$ 6,834,000	$ 6,834,000
Incremental Design Benefit	$ 0	$105,090,000	$179,968,000
Incremental Construction Benefit	$ 0	$ 48,766,000	$180,368,000
Total Incremental Benefits	$ 0	$153,856,000	$360,336,000
Benefit/Cost Ratio – ROI			
Design Benefits Only	1.0 –	2.33 26.13%	2.05 30.36%
Design & Construction	1.0 –	3.42 34.26%	4.10 48.58%
MC Design Issues/Resolution			
Coordination	Communication and coordination left to individual participants; process subject to delays, omissions, and duplication	Structured inputs and outputs and standard applications programs facilitate coordination. No change in method of communication, which is left to individual participants.	Computer stores all information in Facility Description or accesses project-independent information from data files. All latest information is available on command by user; automatic identification of spatial interferences, conflicting criteria, conflicting documentation, etc.
Timeliness	Manual document production, cross-checking, and correction is a time-consuming process subject to human error.	Document production time is decreased, but still requires manual cross-checking and review. Some improvement of timeliness of changes.	Automated cross-checking, conflict detection, and review. Changes are implemented faster and apply to all documentation through the Facility Description. Rapid access to current document status.
Product Quality	Subject to errors, omissions, and conflicts due to lack of coordination and communications.	Improved analysis and subsystem design. Susceptible to errors, omissions, and conflicts due to poor interdisciplinary communication and coordination.	Improved analysis and subsystem design; automatic identification of interference and conflict at time of occurrence will eliminate a majority of errors and conflicts. Facilitates optimization of design and more thorough design review.

alternative will have on specific issues related to MC design. Automation in the stand-alone alternative provides opportunities for improved design efficiency. However, communications and coordination are still left to individual participants in the design process, and are therefore subject to human error and misunderstanding. In contrast, the integrated CAEADS will indicate errors and conflicts in design documentation at the time of occurrence, preventing future design development until the conflict is resolved. This capability will insure that all elements of a design will be compatible with each other. The fact that all design information resides in a single design data base accessible by all disciplines further limits the possibility that any design participatnt will use outdated or incorrect information.

d. Conclusions and Recommendations. The comparative analysis indicates that the integrated CAEADS alternative is a significantly superior system providing improved end-products, more timely production of design documentation, and reductions in design and construction costs. The economic performance of the integrated CAEADS alternative over the 12-year development/use period further supports the conclusion that this alternative represents the best approach to performing MC design. Therefore, it is recommended that the integrated CAEADS alternative be adopted.

CHAPTER 6

CAEADS PROJECT MASTER PLAN

a. Project Master Plan. The current Project Master Plan (PMP) provides a concept for the development, implementation and use of CAEADS over the 12-year period from FY 1978 through FY 1989. The plan covers development tasks, support tasks, and use of the system. Development tasks include Research, Standards Development, Advanced System Design, System Programming, Applications Design, Applications Programming, Data Conversion, Procurement, System Test, and Operations Design. The support tasks include Training Preparation, Training, User Advisory Group Participation, and Outside A/E Group Participation. Use of CAEADS as part of the MC design process is the central task of the plan. The planned stages (below) and the activities and products of each stage will be modified as the master plan is kept current in the future.

The implementation plan is divided into five stages:

CAEADS I - Coordinated Components
in use mid-1980 to mid-1982;

CAEADS IIA - Basic Integration
in use mid-1982 to end of 1983;

CAEADS IIB - Enhanced Integration
in use beginning of 1984 to mid-1985;

CAEADS IIC - Extended Integration
in use mid-1985 to end of 1985;

CAEADS IID - Post-Development
in use beginning of 1986 to end of 1989.

Each stage produces a specific level of system use and of associated development and support tasks. The sequence of stages presents the user with an orderly expansion of the capabilities of the system. In CAEADS I, a limited number of CAEADS capabilities are provided through a single, coherent mode of user-machine interaction. In CAEADS IIA, the capabilities are integrated to provide a common operating environment, and in CAEADS IIB, they are extended by introduction of the Facility Description. In the remaining stages, the capabilities are extended to the full capabilities of the system.

Figures 6-1 and 6-2 show the abbreviated Project Master Plan schedule together with the characteristics of each stage and the applications provided in each stage.

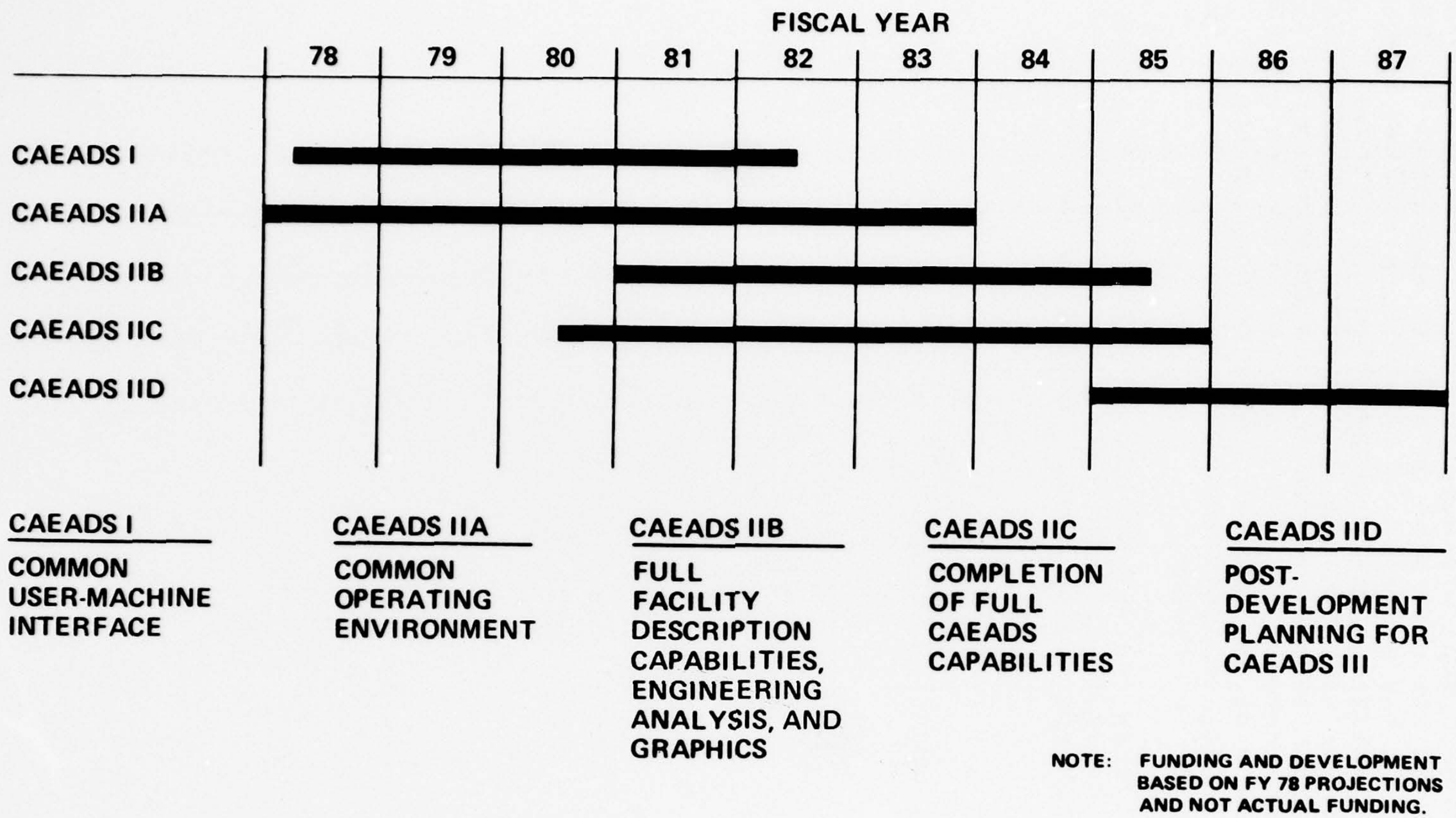
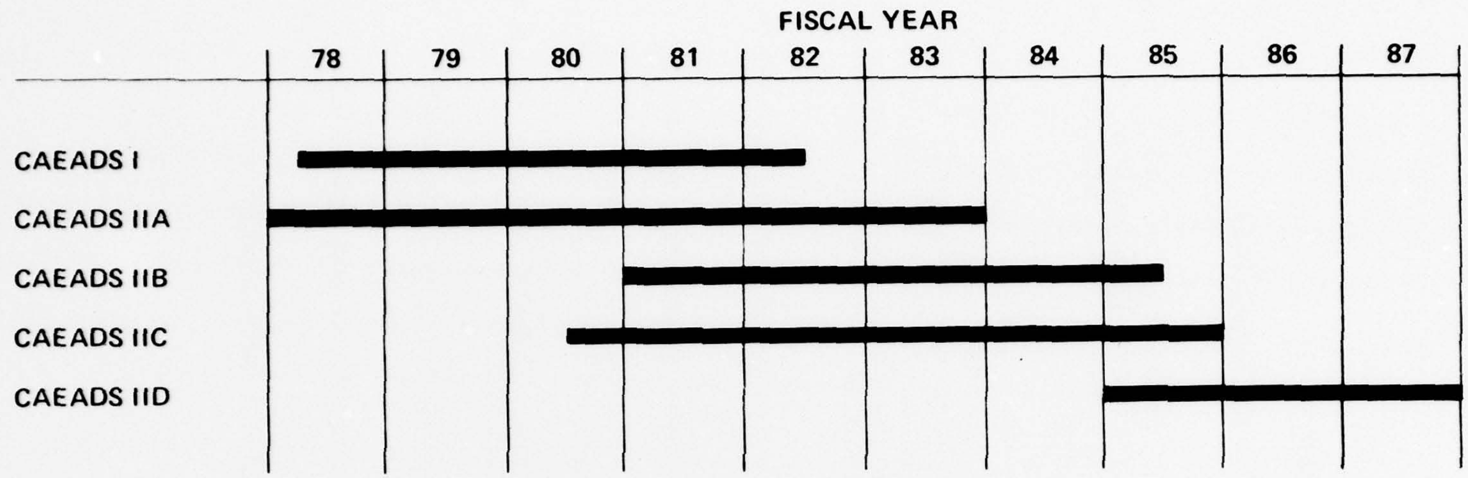


Figure 6-1. CAEADS master planning characteristics.



CAEADS I	CAEADS IIA	CAEADS IIB	CAEADS IIC	CAEADS IID
EDITSPEC (1) COST ESTIMATING (1) 1391 PROCESSOR (1) SEARCH BLAST CEUP	EDITSPEC (2) COST ESTIMATING (2) FUNCTIONAL REQUIREMENTS (1) DESIGN CRITERIA (1) FACILITY DESCRIPTION (1) ENGINEERING ANALYSIS (1) GRAPHICS (1) PDB 1391 (2)	FACILITY DESCRIPTION (2) ENGINEERING ANALYSIS (2) GRAPHICS (2) REVIEW (1) MASTER PLAN DATA BASE FUNCTIONAL REQUIREMENTS (2) DESIGN CRITERIA (2)	FUNCTIONAL REQUIREMENTS (3) DESIGN CRITERIA (3) REVIEW (2)	STATE-OF-THE ART IMPROVEMENTS

NOTE: NUMBERS IN PARENTHESES INDICATE LEVELS OF CAPABILITY

Figure 6-2. CAEADS master plan applications.

CHAPTER 7

ORGANIZATION AND PERSONNEL PLAN

a. Purpose and Scope. The Organization and Personnel Plan (OPP) presents sufficient manpower and qualitative personnel information to enable OCE to foresee strength and skill changes resulting from CAEADS.

For CAEADS, Department of the Army Table of Equipment and Table of Distribution and Allowances (TOE/TDA) documents are unaffected. Only Corps equipment and personnel are directly affected. Uniformed military personnel are affected negligibly, if at all. Training will be done by the Corps for both the Corps and other Army agencies and will not affect other Department of the Army training programs.

b. Approach. The following major assumptions are made for the OPP (dollars are FY77).

(1) Base Years. The base years for strength and skill changes are:

(a) Current year — FY77

(b) The first year CAEADS is forecasted to be in reasonably steady-state operation — FY87

(2) Construction, Operation, and Maintenance Benefits.

(a) Annual construction and operation savings (no maintenance savings) — $10,000,000

(b) Supervision and administration cost rate — 5%

(c) Average construction employee is GS 10/2; annual cost with fringe benefits and overhead is — $30,000

(3) Engineering and Design Benefits.

(a) Annual engineering and design savings	None
(b) Annual added computer machine costs offset by reduced manpower costs	$2,500,000
(c) In-house design percentage of total design	20%
(d) Design cost as a percent of construction cost	6%
(e) Government Architect/Engineer (A/E) contract management cost as a percent of A/E contract cost	33 1/3%
(f) Average engineering and design employee is GS 11/5; annual cost with fringe benefits and overhead is	$36,000

(4) Construction Workload.

(a) Total annual military construction program (less Saudi Arabia), FY87	$1,800,000,000
(b) Percentage of total program (no Saudi Arabia) to be automated by FY87	66 2/3%

(5) Hardware Support.

(a) Large regional computers	2
(b) Small local computers	20

(6) Manpower Support - Automatic Data Processing (ADP).

(a) Available, Aug 77, in affected installations	239
(b) CAEADS computer program and data base maintenance personnel, FY87	32
(c) Contractor personnel	0

c. Results. Summary estimates of the eventual CAEADS impact on the Corps of Engineers organization and personnel are given below. The estimates, based on many assumptions regarding future events, should prove to be reliable mean values; the eventual figures might be two-thirds to three-halves the values shown.

Engineering positions		
Upgraded, transferred, or eliminated	800	(100%)
Upgraded to some extent	686	(86%)
Transferred to ADP	80	(10%)
Eliminated	34	(4%)
Construction positions eliminated	16	
Spaces transferred geographically	54	

CHAPTER 8

RESULTS, CONCLUSIONS, AND RECOMMENDATIONS

a. Results. AR 18-1 Planning and Definition Phase documentation (functional and resource requirements) has been produced and is summarized below.

(1) Updates to the GFSR have clarified the scope of CAEADS. It includes support for the three phases of MC design.

(2) The CAEADS Economic Analysis compared the current Corps design system with two alternatives: stand-alone applications packages and integrated CAEADS. CAEADS was found to promise significantly greater benefits than the other alternative.

(3) The DFSR provides a comprehensive presentation of the MC design functions by project phase, activity area, and discipline. It also furnishes estimates of system workloads based upon the requirements of a typical project. Requirements are to be the basis for advanced system design by identifying the portions of the overall system for which common software modules need to be developed and suggesting the kinds of internal interfaces to be specified by the system designers.

(4) The Project Master Plan identifies and describes the tasks required for the development, implementation and use of CAEADS during the next 12 years.

(5) The CAEADS Preliminary Hardware Analysis presents the hardware/software framework proposed for advanced system development.

(6) The Organization and Personnel Plan presents manpower space requirements and position classification distribution estimates.

b. Conclusions.

(1) CAEADS development and implementation are technically feasible. The most critical area is the three-dimensional Facility Description data base. The development of this capability is likely to require some advances in the start-of-the-art before full implementation can be realized, but existing software which can provide a base for further development has been identified in a related study[2].

(2) The successful development of CAEADS requires the adoption of design and programming standards for the entire system and its constituent subsystems. This will assure common user interaction with all parts of the system and provide maximum sharing of software modules among subsystems in the interest of commonality, flexibility, extensibility, and reliability.

(3) Continued management commitment at OCE and CERL will remain critical for CAEADS, just as they are critical for any project with its scope and complexity. Beginning with the approval of the DFSR and PMP, continuity of the CAEADS design team activities for uninterrupted effort toward advanced system design and implementation, and adherence to the action plan are especially important.

(4) The economic analysis implies that the primary direct benefits of CAEADS will accrue from savings in the cost of facility construction and operation and from savings in cost of design.

(5) After CAEADS has been implemented, an eventual reallocation of resources among the two design phases can be expected. More analysis of alternatives during Concept Design is anticipated. As life cycle cost comparisons and building energy analyses become routine for all but the smallest projects, more extensive analyses will permit more detailed definition of optional subsystems. There will be a corresponding decrease in the effort devoted

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[2] Mitchell, W.J., Oliverson, M., Computer Representation of Three-Dimensional Structures for CAEADS, Technical Report P-86/ADA052040 (CERL, February 1978).

to Final Design, as most construction drawings will be produced directly from the computer-resident Facility Description.

(6) Practical experience is needed concerning the application of computer aids to the specifics of Corps design practice, as well as the human factors involved in interacting with computer-resident design information and procedures in order to verify the results of this study. Feedback from carefully designed studies of existing systems in use on selected Corps projects can contribute to the advanced system design of CAEADS and can supply more detailed system workload data for both the existing and the proposed systems.

c. Issues To Be Resolved. Major issues relating to the use of CAEADS by architectural and engineerng firms under contract to the Corps include: how contractor terminal station equipment will be paid for, policy for contractor use of CAEADS software on Corps projects, source and amount of contractor personnel training in the use of CAEADS, and other policy related issues. These issues are of extreme importance in view of the fact that approximately 80 percent of Corps of Engineers work is performed by outside A/E firms under contract to the various District Offices.

The issues of A/E access to CAEADS functions, (whether A/Es will set up terminals in their offices, will use centrally located terminals in Corps Districts and other design offices, or whether A/E firms will have access to CAEADS at all) need to be carefully evaluated and policy recommendations formulated for CE decision.

d. Recommendations.

(1) The development of the integrated CAEADS should proceed in accordance with the proposed Project Master Plan.

(2) The Corps of Engineers should continue its present commitment of resources to CAEADS, including allocation of high-level management responsibility. CAEADS is a large project and will not be implemented successfully without a major commitment to control, coordinate, and fund its development.

(3) End users, especially District Offices, should continue to be consulted frequently during CAEADS advanced design and development. The experience of users with various prospective subsystems and the recommendations of users will continue to be valuable inputs to system development.

(4) An advisory group from the private sector consisting of A/E's, suppliers of engineering software and processing services, and computer-aided design system developers in related fields should be formed to play an advisory role similar to that of the Field Users Advisory Group, which is representative of government users (Corps Division and District offices and major Army commands), and a permanent group established by OCE.

(5) Separate economic analyses and DFSR's or equipment documents should continue to be required for prospective and new CAEADS subsystems. These documents should conform to the overall requirements of CAEADS.

(6) Policies for access to and use of CAEADS by A/E firms should be developed by OCE in close consultation with the user advisory groups. There appear to be significant unresolved issues related to the extensive introduction of publicly developed computer aids into existing professional practice.

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